135

THIRD

REPORT

FROM THE

SELECT COMMITTEE

ON THE

ROAD

FROM LONDON TO HOLYHEAD;

&c.

MENAI BRIDGE.

Ordered, by The House of Commons, *to be Printed,*
29 *April* 1819.

256. E

THE REPORT - - - - - - - - - - - - p. 21
MINUTES OF EVIDENCE - - - - - - - - - 25

THIRD REPORT.

The SELECT COMMITTEE appointed to inquire into the state of the Road from *London* to *Holyhead* by *Coventry* and *Shrewsbury*; into the regulations for the conveyance of His Majesty's Mail between *London* and *Dublin*, and between *Liverpool* and *Dublin*, and from thence through the interior of *Ireland*; and into what Improvements may be made in the accommodation of Persons embarking and disembarking at *Holyhead* and *Howth* respectively; and to report their Observations thereupon; together with the Minutes of the Evidence taken before them, from time to time, to the House; and to whom the several Papers relating to the *Menai Straits*, which were presented to the House, upon the 18th day of *February* last, were referred:——Have, pursuant to the Order of the House, further examined the Matters to them referred; and have agreed to the following REPORT:

YOUR Committee have proceeded to inquire into the subject of the Papers referred to them by the House, containing Mr. Telford's Plan for building a Hanging Iron Bridge across the *Menai Strait*, and the Evidence taken last year by the *Holyhead* Road Commissioners.

With the view of being able to lay before the House all that could be advanced to prove the practicability of this Plan, Your Committee examined Mr. Telford concerning each specific part of it, and they then examined Mr. Rennie, to ascertain how far he concurred in the calculations and opinions of Mr. Telford; they also examined Mr. Donkin, whose attention has been for a considerable time applied to this principle of Bridge-building, and who ranks very high as a civil and practical Engineer, and is Chairman of the Committee of Mechanics of the Society of Arts and Manufactures.

In order to bring the whole subject before the House in the most distinct manner, it appears to be advisable to treat of it under the following heads:—1: The Abutments.—2: The Iron Work.—3: The Strength of the Bridge.—4: What probable Undulation or side Vibration.—5: What Contraction or Expansion.—6: The Means of Repairing the Bridge.

1: The Abutments.—The Abutments will consist of the whole of the Masonry Work which is expressed on the Plan; each of the two principal Piers will be 60 by 42½ feet at high water mark, having a foundation of Rock. These Piers when connected with the whole of the remainder of the Masonry will form a mass constructed with blocks of hard Limestone, of much greater power than is requisite for supporting a Bridge of this kind. Mr. Rennie being asked this question, "Can there be any difficulty in making the Piers capable of bearing the Bridge?" answered, "None in the world;" and explained to Your Committee, that it was equally practicable to make a Pier to sustain a weight drawing inward, Evidence, p. 27.

as this Bridge will draw, as to sustain a weight pressing outward, in the way an arched Bridge presses: from thence he argued, that the lateral tension of the proposed Bridge would not occasion any difficulty. He mentioned that the lateral pressure of the side Arches of the *Southwark* Bridge was about 3,700 tons, and that this was infinitely greater than the strain of Mr. Telford's Bridge.

Upon the summit of each of the two main Piers will be erected a frame of Cast Metal, of a pyramidical form, for the purpose of raising the Cables, from which the Bridge is to be suspended. As the Cables will be carried from the tops of the pyramids, so as to form nearly similar angles on each side of them, the pressure will be almost perpendicular; and Mr. Telford says, "It is quite impossible the weight of the Bridge can crush them, in consequence of the well ascertained fact, that it requires a weight of from four to five tons to crush a cube of a quarter of an inch of good Cast Metal."

Evidence, p. 30.

2: The Iron Work.—Mr. Telford proposes to have four lines of suspension in the breadth of the Bridge, by which means his Cables will be disposed in such a manner, as to divide it into two Carriageways of twelve feet each, and one Footway in the centre of four feet. Along each line be will have four Cables, making in the whole sixteen; these Cables will pass over Rollers fixed on the summits of the Pyramids, and be fastened at their extremities to an Iron frame, lying horizontally over the tops of the small Arches, and under a mass of masonry, as described by the dotted lines on the Plan.

Evidence, p 25.

From these Cables the Roadway will be suspended by vertical Iron rods, connected at their lower extremities with wrought iron bars, both transversely and longitudinally, thus forming a frame on which timber will be laid for the Roadway.

Mr Telford intends to make a temporary Wire Bridge from one abutment to the other, in order to carry over the Cables, and arrange the several parts of the Bridge.

3: The Strength of the Bridge.—Mr. Telford informed Your Committee, that for many years past he has bestowed great pains and considerable expense on making experiments for the purpose of ascertaining the strength of malleable iron: he says, in his Evidence, that he has not made less than 300 experiments upon iron, from one-twentieth of an inch to two inches in diameter, and from 30 feet in length to 900 feet; that he has made them vertically, horizontally, and with a variety of different degrees of curvature; that he has combined iron into the shape in which he has proposed to make the Bridge, in a model of 50 feet in length, and tried experiments upon it. That the greatest part of his experiments were made from absolute weight, by tearing iron to pieces by mere weight, and that all his calculations were founded upon the true and actual strength of iron, as proved by the weight it would sustain before it would stretch or break asunder. In respect of the larger pieces of iron, which could not conveniently be torn asunder by weight only, Mr. Telford made several experiments upon the strength of it, by means of an hydraulic press of Mr. Brunton's, made on Mr. Bramah's principle, and by this it appeared, that it required a weight of from 26 to 30 tons to tear a square inch bar asunder; similar experiments have been tried with other machines, which gave very nearly the same result. Mr. Rennie and Mr. Donkin, in their Evidence, entirely agree with Mr. Telford's statement of the absolute strength of malleable iron. Mr. Rennie recommends, that this Bridge should be constructed, so as to be four times beyond the strength

Evidence, p. 29.

Evidence, p. 29.

strength requisite to carry its own weight; that is, to make it something stronger than it is proposed to be made by Mr. Telford: but Mr. Telford says, there will be no difficulty in giving it such an additional degree of strength, for by increasing the quantity of iron, you may gain any additional power. Evidence, p. 27.

Mr. Telford submitted the whole of his experiments to the examination of Mr. Barlow, who is the Mathematical Master at Woolwich Academy, and who has published the greater part of them in his Work on Timber and Iron. Mr. Barlow states, that the theoretical calculations which he has made, correspond with those which are deduced from practical experiments.

It appears by Mr. Telford's Evidence, that the weight his Cables will support before they will break is 2,016 tons, exclusive of their own weight: the weight of the Bridge, exclusive of the Cables, is 342 tons; therefore, the Bridge will bear 1,674 tons beyond its own weight.

Mr. Donkin, on being asked whether it appeared to him that the different calculations of strength made by Mr. Telford were accurate? replied, "Mr. Telford seems to have taken his primary data from the fact of a bar of iron, one inch square, beginning to stretch at half its absolute power; in all the experiments that I have witnessed of straining iron, I think none of the bars began to stretch permanently under nearly two-thirds of it; it appears to me, therefore, that Mr. Telford's data are perfectly safe." Evidence, p. 32.

4: UNDULATION and SIDE VIBRATION.—Mr. Telford says, there is not much reason to expect undulation from any weight being laid on any particular part of the Bridge, in consequence of so great a weight as 489 tons (the weight of the whole Bridge) hanging between the points of suspension; but to guard against it, he proposes to make the four sides of the Roadways of framed Iron-work, to be firmly bound together for 7 feet in height, and to have similar work for 5 feet in depth below the Cables; so that when they meet towards the middle of the Bridge, they will constitute a frame-work of 12 feet deep on each of the Roadways, which will also form a complete protection to Passengers. In respect to side vibration, Mr. Telford says, the proportion which the breadth of the Bridge bears to the length of it, will keep it quite steady.

Mr. Rennie says, "This Bridge being to be covered with Timber, it makes a single plank of 522 feet long and 30 feet wide, and I conceive that the shock can scarcely be any thing sideways:" and on his being asked by the *Holyhead* Road Commissioners, "What effect do you apprehend the wind would have upon a Bridge of this construction?" answered, "My opinion is, that from the strength of the Iron and the weight of the Bridge taken together, there would be no injury in that way." Evidence, p. 27. See Evidence, p. 16, printed Papers.

5: CONTRACTION and EXPANSION.—On these heads Mr. Telford and Mr. Rennie calculate, there may be a rise or fall to the extent of four or five inches; but both agree, that the changes arising from the temperature will not derange the Bridge.

6: REPAIRS.—It appears from the Evidence, that the Cables, suspending Rods, and Roadways, will be so constructed and united together, that each part may be taken out and repaired separately. Evidence, p. 31.

Your Committee feel great satisfaction in having it in their power to say, that Mr. Telford has completely convinced them of the practicability of his plan. The numerous instances which he has already given to the public of his talents as a civil Engineer, fully prove that the House may place great confidence in his opinion. But when his opinion is supported by Mr. Rennie and other Engineers, the case of the practicability of this undertaking appears to be as completely made out as it is in the nature of things to allow of its being established.

When it is remembered, that the first Estimate prepared for Lord Colchester (when Chief Secretary for *Ireland*) for building a Cast Iron arched Bridge across the *Menai* amounted to 268,500 *l.*, Your Committee are of opinion, that the Public stand greatly indebted to the industry and talents of Mr. Telford, for having contrived a plan on so secure a principle, for executing this work for the sum of 70,000 *l.*

29 *April* 1819.

MINUTES OF EVIDENCE.

SIR HENRY PARNELL, BARONET, IN THE CHAIR.

Sabbati 24° die Aprilis, 1819.

Thomas Telford, Esq. Called in, and Examined.

Thomas Telford Esq.

HAVE you read the evidence upon your plan of a bridge over the Menai Strait, which has been printed by order of the House of Commons?—I have.

Have you any observations to make upon that evidence?—Yes, I have a great many, which I took the liberty of putting down on paper, thinking that would be the shortest way of informing the Committee of my ideas concerning the bridge.

[*It was delivered in, and read, as follows.*]

" *Menai Bridge.*

" On perusing the printed evidence which was taken upon this subject last year, I observe, that although the concurrence is general as to its practicability, yet that in the particular discussions, although ably and fairly conducted, inaccurate data have been assumed: I therefore consider it may be useful to state, shortly, the outlines of the plan which I have proposed to the Commissioners for the Holyhead Roads, as the most economical and suitable for improving the communication across the Menai Strait.

" In order to avoid interrupting the navigation, it is evident that a horizontal roadway is most advisable, and to obtain this, a Bridge, upon the principle of suspension, seems unavoidable; it is therefore adopted at the height of 100 feet above the high water of spring tides. The distance between the points of suspension is 560 feet, and the versed line is 37 feet or about 1-15th of the chord line. The breadth of the bridge will be about 30 feet, having two carriageways of 12 feet each, and a footpath of four feet between them. This affords four points of suspension in the breadth of the bridge. The whole roadways are to be suspended from the main cables by means of perpendicular rods, and are therefore to be considered as mere weight. The iron-work of the cables and timber of the roadways are to be constructed so that they may be taken out and replaced separately.

" By calculation I find that the weight to be suspended is 342 tons: by numerous experiments which I have made to ascertain the strength of malleable iron, it appears, that with a chord line of 560 feet, and a versed sine of 37 (or a curvature of 1-15th), a bar of good iron, one inch square, will, besides its own weight, carry 10 ½ tons, and about one half of that weight before it begins to stretch. For the Menai bridge, I have taken a section of 192 square inches, which at 5 ¼ tons to each square inch, will support 1,008 tons being a surplus of 666 tons above the real weight of the bridge, and there would be required a further weight of 1,008 tons to break down the bridge: this I conceive is making ample provision against any probable trial to which such a bridge can be exposed. From the elevation it will be seen, that the cables attain their curvature by passing over cast iron frames part of which are of a pyramidal form, and the other parts are connected with the top of the masonry; from thence it will be seen, by dotted lines, that these cables pass down the masonry to another cast iron frame, laid horizontally along the top of the arches, and connected with their springers by means of perpendicular rods, thereby embracing the whole mass of masonry and spandrels, making in all about 12,000 tons at each end of the bridge, and this exclusive of the great pyramids. As the weight of the bridge between the two points of suspension, including the cables, is 489 tons, there is not much reason to expect undulation from any weight which will be laid on any particular part; but to guard against any effect of that sort, I propose making the four sides of the roadways of framed iron-work firmly bound together for seven feet in height, and similar work for five feet in depth below the cables, which when they meet towards the middle of the bridge will constitute a frame-work of 12 feet deep.

Thomas Telford, Esq.

"With a bridge 30 feet in breadth, and 532 feet in length, there is not much to be apprehended from side vibration; but in order to provide against this operation, I have in the plan placed two horizontal cables, crossing the bridge diagonally, each laying hold of the middle of its length, and passing round a cast iron projecting frame, at the opposite sides of the great pyramids, is from thence carried to the masonry of the abutments; thus creating a diagonal stay upon 70 feet in breadth.

"When it is considered that from 4 to 5 tons are required to crush a cube of one-quarter of an inch of good cast iron, there can be no doubt of the sufficiency of the cast iron frames over which the cables will pass.

"These cables are continued to the cast iron frames which connect the masonry of the abutments. The weight of the bridge is 489 tons, upon which, if 300 tons additional are placed, they make 789 tons. The pull of this weight at the abutments, upon a curvature of one-fifteenth, is found by my experiments over a pulley, with a perpendicular weight, equal to about two and a half times the weight on the other side, or 1,972 tons. To counteract this, the cables are, as has already been observed, continued at nearly the same angles as those of the bridge, to the cast iron frame, which embraces about 12,000 tons of masonry, and to which much more if necessary might be connected.

"With regard to any change by contraction or expansion, it is known from experiments, that with a difference of temperature of 90 degrees of Fahrenheit, the difference of length of iron would only be $\frac{6}{10000}$, or about 5 inches upon 700 feet, and as the iron-work would most likely be put up at a mean temperature, the contraction would be two and a half inches, and the expansion an equal quantity, which would not derange the bridge; but if the main suspending cables were covered with some substance, which was an imperfect conductor of heat, and which is intended, the above variation of 90 degrees of temperature could not take place.

"I have thus, for the satisfaction of the Committee, stated the principal circumstances relative to this plan, and which have induced me to recommend it. The numerous and tedious details which are connected with such a work, I presume the Committee do not expect me to go into here; and as the having a suitable and substantial bridge is the sole object in view, I shall most thankfully receive any useful improvements that may be suggested by others.

(Signed) "*Thomas Telford.*"

"Dated, London, 23d April, 1819."

John Rennie, Esq. Called in, and Examined.

John Rennie, Esq.

HAVE you any observations to make upon the evidence you gave to the Holyhead Road Commissioners last year?—There are two or three words taken down wrong. The words, instead of "bore upon an average from 25 to 26 tons, very few indeed bore 26 tons square inches;" instead of square inches, it should be, per square inch, in page 14.—In page 15, within eight lines of the bottom, "I had it in contemplation to use chains for the purpose of," the word here is "strengthening," it should be "setting."—In page 16, the question is, "What effect do you apprehend the wind would have upon a bridge over that Strait, of such a construction as that to which the commissioners allude?" this seems to be taken down wrong; the words are, "My opinion is, that from the strength of the tide,"—the strength of the tide has nothing to do with an iron bridge,—my opinion is, that from the strength of the iron and weight of the bridge taken together, there would be no injury in that way.

Have you seen any instances of bridges upon this construction of a large size?—No, I have not; the only thing of that kind I have seen is a model that was made by Captain Brown, who is an iron cable manufacturer at Mill Wall, Isle of Dogs, of a bridge nearly of this construction, of 120 feet span, and over which I was drawn in a carriage, and found myself perfectly safe and easy.

Where was that bridge erected?—At Captain Brown's manufactory, Mill Wall, Isle of Dogs, on the land, merely as an experiment; and I suppose it is standing yet, where I believe it may be seen at this day; I came out of the carriage, and made the coachman drive several times over it, that I might see how it acted.

There was no vibration?—Very little vibration.

Can you calculate the weight that would be distributed on such a bridge as this of Mr. Telford's, supposing it was filled as full as might be with a drove of oxen?—I cannot answer that question off hand.

[To

John Rennie, Esq.

[To *Mr. Telford.*] Can you answer that question?—The weight, as far as I can calculate, of covering it with oxen will be about three hundred tons, it depends on the weight of the cattle; but in the usual way of driving cattle, there is never that quantity together, that is, supposing the whole bridge covered from end to end, and no void space left, which is a very unusual thing. In driving cattle, nobody ever thinks of driving 200 head all in a heap.

[To *Mr. Rennie.*] What power of resistance beyond the probable weight that could be put upon such a bridge, by cattle or otherwise, should you conceive to be necessary to bear up a bridge of this description?—I think in my last evidence I stated, that if I was to make a bridge of such dimensions as this, I should not think it secure unless it was capable of carrying at least four times its own weight; for instance, suppose the carrying itself was 300 tons, I should make it capable of carrying four times that weight at least, in addition to its own, that is, 1,500 tons; but this proportion would not hold if it was a light bridge. If you will allow me to state with respect to lateral pressure, or rather lateral tension, I should think there is no difficulty in that respect; for in the bridge I have constructed over the Thames, at Queen-street, the lateral pressure of the side arches is about 3,700 tons, which is infinitely greater than any thing that would ever be wanted here.

That being an arched bridge, how does the comparison hold?—The pressure of an arched bridge is outward, the draft of the other is inward, and I conceive it equally practicable to make a pier to sustain the weight inward as outward; and in the experiments I have made, I have found that the force necessary to crush the materials against which the iron acts, is between twenty and thirty times the lateral pressure. I made a set of experiments to ascertain the fact as to the particular kind of stone used in the abutments and piers.

Did you ever see the chain bridge over the Tees?—I never saw it. When the Bell Rock light-house was building, which is about ten miles out at sea, a smith's forge and other matters were erected on a different part of the rock to which the light-house was; and, in order to have a communication for the heavy materials from the forge to the light-house, we had one of those bridges, which answered very well.

What length was it?—Fifty or sixty feet; I do not know exactly, but it was full that, I know. I would observe, that this bridge being to be covered with either planks or wood, it makes a single plank 522 feet long and 30 feet wide, from which I conceive that the shake can scarcely be anything sideways.

Do you entertain any doubts with respect to the practicability of constructing such a bridge as that which is proposed by Mr. Telford, according to the plan which he has just stated to the Committee?—I have no doubt of the practicability of constructing such a bridge; and I presume that Mr. Telford has taken care to have all the parts sufficiently strong, and so well connected together, as to be able to sustain the weight he has calculated it to bear; but I have not made any calculations of the actual strength of the bridge which Mr. Telford proposes, though I am satisfied that a bridge of that construction may be made sufficiently strong for the purpose.

Do you think that the resistance which there is in this bridge, compared with the weight which has just now been given in numbers, is sufficient to insure the bridge against all probability or possibility of risk?—I have before stated, that I consider a bridge such as this is, should be capable of carrying at least four times the weight of itself, and above four times as strong, as a mere theoretical calculation gives it.

But according to the weights, as to which we have been speaking in numbers, is the resistance spoken of in this bridge by Mr. Telford, sufficient to answer what is now said by you?—It requires calculations to prepare one's-self. I presume Mr. Telford has gone to that extent, and that is all I can say about it. I conceive it is requisite to make it bear at least four times its own weight; I have not entered into the calculation, but were I to do so, I should calculate the weight of all materials, and make it capable of carrying four times its own weight.

Can there be any difficulty in making the piers capable of bearing the bridge?—None in the world.

Does not the whole depend merely upon a matter of calculation?—Certainly, and the judgment of the person who puts it together.

You have made no calculation as to the weight and bearing of the bridge?—I never have, because I never saw the plan until it was just now produced before me.

[To *Mr. Telford.*] What greater power of resistance than the actual weight of the bridge itself have you provided for in your calculation?—Rather more than four

John Rennie, Esq.

times the power. The whole of the bridge is 489 tons, and the power of suspension I calculate equal to 2,016 tons.

What is the sectional area of your cables?—I have given the relative power to the weight; it is more than four times.

State the sections of your cables?—The section of the cable (taking it as a single cable) is 192 square inches.

[To *Mr. Rennie.*] Will a bridge, constructed upon these data, be sufficient to bear a power of resistance four times greater than its own weight?—I should think it would; but if it was my own case, I should make it a little more, that is to say, I should make it four times beyond the strength requisite to carry its own weight.

[To *Mr. Telford.*] Would there be any difficulty in giving this bridge that additional strength?—None at all; only the additional expense of that quantity of iron; you may have any quantity of iron which will give the proportional power.

[To *Mr. Rennie.*] Will you explain to the Committee your reason for suggesting this increase of power?—I have found, from the experiments that I have made upon pulling bars of iron asunder, that generally speaking (for they vary very much) about two-thirds the weight that will break it, begins to stretch it; and I have reason to believe, that if that weight was to be continued a very long time, it would ultimately tear the bar asunder; consequently, a bar of iron capable of bearing twenty-four tons before it broke, I calculate, in a work of this kind, at only sixteen, namely, the point at which it would begin to stretch; and therefore, if it was made four times that, I should think it would be perfectly sufficient, which you will find amounts to nearly five times the weight of the bridge. If it will carry four times in addition to its own weight, I consider that sufficient.

Do you think that any external preparation would prevent the stretching of the iron by the variation of heat?—That is a question I cannot answer: I should doubt it. I have not made any experiments upon it, but I can state a fact with respect to the Southwark Bridge. The middle arch, which is 240 feet span, rises 3-10ths of an inch perpendicular for every variation of ten degrees heat; but then it requires the heat to be continued at least five or six hours before the bridge comes to the temperature of the atmosphere, and sometimes more.

Do you conceive that the degree of contraction or expansion, to which this bridge would be subject, would in any degree contribute to derange it?—If it is made strong enough, I think not: if it is made according to the strength I have named, I think not.

Will the strength of the bridge, which depends upon the quantity of iron, at all prevent its expanding or contraction?—The larger the quantity of iron, so much the longer will it be in coming to the temperature of the atmosphere, but I am not aware it will prevent its contracting or expanding: it will be so many hours longer of coming to the temperature of the atmosphere; and if it is longer in coming to the temperature of the atmosphere, it will be so much longer before the variation takes place. When I spoke of the Southwark Bridge being five or six hours coming to the temperature of the atmosphere, I spoke of it before the road was laid on. I have had no opportunity of trying it since. I suppose it will be much longer of coming to the temperature of the atmosphere now than it was before the road was made.

What was the greatest rise you ever observed in the centre arch of the Southwark Bridge?—About two inches and a quarter perpendicular; I think we have had a variation of from 22 degrees to 92, 93, or 94.

Supposing the same effect to be produced upon this bridge, which is something more than double the span, what would be the effect as to the disturbing any part of the solidity of the bridge?—From four to five inches would be the perpendicular rise by contraction or expansion; but I do not think, that if the bridge is made of the strength I have named, there will be any thing to fear from that.

[To *Mr. Telford.*] How many cables do you intend to make use of to suspend this bridge?—According to my present opinion, upon consideration of the subject, I would prefer having four cables over each point of suspension (making 16 in all) between which the suspending rod would pass, and depend upon each two of them, so that taking one away would not materially affect the general strength.

What is the weight of the chain per yard, of each separate cable?—117 pounds per yard.

In what manner do you propose making your cables?—I propose to construct them of a number of straight bars connected together at different lengths; I have not yet

Thomas Telford, Esq.

yet entirely decided at what particular length they should be joined, or whether it would be preferable to unite a certain number of them by welding, and connect each of those lengths by joints.

What will be the total weight of each cable between the points of suspension?—From what we have now made out between the points of suspension, each cable will weigh nine tons and three quarters.

And if that cable were suspended in a shaft, what weight would it take before it began to expand perpendicularly?—By this hasty calculation, which I hope is correct, 162 tons, exclusive of its own weight, and that depends upon the length employed.

At what weight do you suppose the tension of the iron would commence?—At one half the weight that would break it.

What is Mr. Rennie's calculation?—Two-thirds of that weight.

Then in fact Mr. Rennie and yourself, agree in your estimate as to the power of the bridge?—Precisely so; because the relative powers are as twelve to sixteen, which gives the fourth of additional power, which Mr. Rennie requires.

Can you inform the Committee the manner in which you propose the bars to be united, of which the cables are to be formed?—I should not wish, by what I am going to say, to confine myself to any particular form, because future experiments may lead to a more perfect one; but I have sketched out a form of joining, in order to convince the Committee that it is perfectly simple and practicable.

[*It was delivered in.*]

Do the Committee understand your drawing correctly, in concluding, that supposing the two external bars not to devaricate, a circumstance which the position of the wedges appears to insure, and so great a strain to be created as to force the cable to break somewhere, the fracture must ensue somewhere else than at the joining, or in other words, that the joining is the strongest part of the cable?—I mean distinctly to say so.

Have you bestowed any very particular attention in making experiments upon the strength of iron, in order to form data upon which you have proposed this plan of a bridge?—I have for many years past bestowed great pains and great expense upon making experiments for that purpose; I dare say I have not made less than three hundred experiments; I have made them upon iron from one-twentieth of an inch to two inches diameter, and from 30 feet in length to 900. I have made them vertically, horizontally, and with a variety of different degrees of curvature; I have combined iron into the shape in which I have hitherto proposed to make the bridge, and tried experiments upon it in a model of 50 feet in length, and I have a register of these actual experiments here, for the Committee to see that what I have stated have had due attention; and it is upon these elementary parts that my data are founded.

By what machines has the strength of iron been ascertained, upon which your data is calculated?—I performed the greatest proportion of these experiments without the intervention of a machine, but from absolute weight, tearing the iron to pieces by weight; upon the larger pieces of iron, which could not conveniently be subjected to being torn to pieces by weight, I performed the experiments by means of an hydraulic press, made upon Mr. Bramah's principle, for the purpose of proving chain cables, at Mr. Brunton's manufactory in the Commercial Road, where these experiments were repeatedly performed in the presence of many different persons.

Do the experiments that have been made by Mr. Bramah's press correspond with experiments made by machines belonging to other persons?—Very near; they give the weight rather more than what either Captain Huddart's or Mr. Brown's does; Mr. Brown's machine is a very good one, it is a combination of wheels and levers acting upon each other; I believe Captain Huddart's was the same, but I never saw it.

The general result, therefore, corresponds in respect to the strength of iron, as proved by these machines?—I have a much better proof for that, the proof of my own tearing it to pieces by actual weight, which is much superior to any machine, for there there can be no mistake. I chiefly rely on the experiments made by actual weight.

What is the weight proved necessary to tear a square inch bar asunder by these machines?—From twenty-six to thirty tons, from the result of all my experiments.

Did you submit your experiments to the examination of Mr. Barlow, the mathematical professor at Woolwich?—I furnished the whole of my experiments to

Mr. Barlow,

Thomas Telford, Esq.

Mr. Barlow, at the time he was publishing his book on the Strength of Materials, not with any view to this bridge, but he thought them valuable experiments for his book.

Do not the theoretical calculations he has published, correspond very much with the practical experiments you have just mentioned?—Very nearly; I do not go from any theory, I proceed upon experiments.

In what way is it intended to throw this long continued cable of 560 feet across the Strait?—My present intention of carrying it across, is in this manner: first having built my abutments up to the height of the roadway, I establish a communication with the two sides; I then pass along from one abutment to the other a number of very small chains, or more probably strong wires, and I fix them firmly upon each abutment, and in such number as shall form a convenient roadway for the first cable, and having passed that over, I can by its means and the same temporary road carry over all the rest.

Of what thickness will these wires be?—That is just according to the power that I want, and the weight I lay upon them; I imagine the tenth of an inch will be quite sufficient, because they are easily managed, and it is only laying an additional number across.

What will be the curved line of a wire, the tenth of an inch in thickness, of the given length of this bridge?—I can draw a wire of that diameter within two feet of the straight line, but it would not be so strong as I could wish it, and therefore I would give it a greater curve, because the weight it would bear is according to its deflection.

What would be the necessary deflection?—I am not aware of that. With regard to the main cables themselves, which is the great object, I would construct them on the bank, probably on the Carnarvonshire shore, pass them over the pyramid and along the temporary roadway to the opposite pyramid, raise them over it, continue them down to the masonry abutments, where they are to be fixed, and so successively till each of the supporting cables were in their places and properly adjusted; I then hang on my perpendicular rods, and construct the roadway; having that done, I proceed with my side frames, which form the parapets along each side; the same under the principal cables, which, when united near the centre, will, I expect, prevent all perpendicular undulation.

Is the Committee right in supposing that those perpendicular rods will tie up the floor and keep it in its position?—It is; and they are kept at a distance of five feet from each other longitudinally, that the suspending power may be equally distributed over the whole length.

Would any additional strength be given by having any shorter chains at intervals, as they are on the land side?—I think the simplicity of the construction would be very much injured by it.

Are the Committee right in supposing there would be no tendency in the weight of the bridge to pull the summit of the two iron pyramids together, but that the whole pressure of the weight will be in a perpendicular line from the vertex to the base of each?—I expect that the tendency to pull the upper extremity of the pyramids inwards, towards the centre of the bridge, will be completely counteracted by the manner in which the cables are distributed towards the abutment, and that it will reduce the whole to a perpendicular pressure.

Is it possible that that perpendicular strain should be so great as to crush the pyramid in a direction from the vertex to the base?—Quite impossible; because we know, by experiments, that it requires from four to five tons to crush a cube of a quarter of an inch of moderately strong cast iron; multiplying this by sixteen, gives what a square inch would sustain, and multiplying that by thirty-six, would give what one of the supports would sustain, which is more than all we want.

Do you propose to adopt any particular precaution at the apex, to prevent the possibility of a strain occurring?—I do; I mean that the cables should not be fastened at the apex of the pyramid, but shall pass over a large cast iron roller, with which the cables will form a tangent, the cables afterwards being continued to the iron frame in the abutment, the strain would ultimately be all carried to that place.

If you suppose weight to be equally distributed throughout the length of the bridge, and indefinitely increased, where do you conceive that your work would give way?—I think that the cables would be torn to pieces near the points of suspension.

Can you form any general opinion as to what quantity of weight, so equally distributed, would be necessary to produce that effect?—At least 2,000 tons.

That

Thomas Telford, Esq.

That is about four times the weight of the entire bridge?—It is.

What is the foundation upon which the pier-work will be constructed?—Rock.

Is the stone that you propose to make use of, particularly fit for this description of masonry?—The finest I ever saw; it is grey marble, perfectly solid, and in large masses.

Do you find it in a convenient situation?—Very much so; there is no earth upon it, it is close to the sea-shore, where we can load it in the vessels, and carry it to the spot without difficulty; it is procured in the north-east end of the island of Anglesey, from the estate of Lord Bulkeley, where the cliffs are nearly 100 feet high; the earth has been washed away by the sea, and many of the stones are lying loose upon the shore, and others are very contiguous to it; and where they can be loaded into flats, by which they can be carried through Beaumaris Bay to that part of the Menai Strait, where the bridge is to be constructed.

Are the foundations of the main piers above low water mark?—They are; one of them is above high water mark.

And are they solid rock?—The one on the Anglesey side is a naked firm rock, that has been for ages exposed to the water and the air; the other is also upon rock, but is in part covered with clay.

Is there the same solid foundation for the piers on the Carnarvonshire side as that of the rock on the other side?—I think it will be sufficiently solid.

Have you ascertained the thickness of the bed of clay no that rock?—The rock is mostly visible, there is not much clay upon it.

Is the rock of the same quality on that side as the other?—It is not of the same kind; it is a sort of bastard free-stone on that side.

Has any thing been done with regard to Runcorn Bridge?—I do not know; all I did there was to make some experiments, for the purpose of enabling me to form a plan for a bridge.

Has this plan been abandoned in consequence of any doubt of the practicability of carrying it into execution?—Not to my knowledge.

Will there be any difficulty in repairing any part of the bridge over the Menai?—I have already said, that both the cables and the flooring, and I may now add the perpendicular suspending rods, will be so constructed and united, that each of the parts may be taken out and replaced separately, therefore I conceive there can be none.

Do you conceive that a horse would be frightened in going over the bridge for the first time?—I do not think he would.

Of what material do you propose the upper stratum of the road to consist?—I have hitherto considered it to consist of soft wood, but I see no objection to covering it with cinders.

What do you mean by cinders?—Cinders from an iron forge.

Do you conceive there would be any danger of a lateral vibration in a violent gale of wind?—I can only confirm Mr. Rennie's opinion, that from the proportion that the breadth of the bridge has as a frame to its extreme length, and with the addition of the diagonal cables, that there can be none.

Do you conceive that there would be any sensible perpendicular vibration on a mail coach passing over?—I conceive there will be none at all.

You say, that this bridge ought to carry four times its own weight to be strong enough; have you calculated the expense of the bridge at that enormous weight that it will be?—Yes.

Bryan Donkin, Esq. Called in, and Examined.

Bryan Donkin, Esq.

YOU are a professional civil engineer?—Yes, I am.

Are you chairman of the committee of mechanics?—I am in the society for the encouragement of arts, manufactures and commerce.

Have you bestowed much pains in examining the principle of building suspended iron bridges?—I have paid considerable attention to it; I had occasion to do so some years ago. I was applied to by a person who took out a patent for building bridges of iron chains, and it led me to make experiments on the practicability of the scheme; that was the first time my attention was called to the subject.

Did you attend any experiments that were made by Mr. Telford to prove the strength of iron?—Yes, I did, at Mr. Brunton's, in the Commercial Road.

Are you particularly conversant in the mechanical process of working iron?—Yes; I am a practical engineer, as well as a civil engineer; I employ men constantly for that purpose.

Bryan Donkin, Esq.

Having heard Mr. Telford's description of the manner in which he proposes to form the cables for this bridge, and other parts of the bridge, are you of opinion, from your acquaintance with the business of iron-work, that the estimates which he has assumed will be sufficiently strong for the purpose?—I have no doubt of it.

Do you approve of that plan which he has proposed for joining together the different lengths of the cables?—I think it a very simple and excellent plan; I think it extremely desirable, in the construction of cable bridges, that bars of iron should lie in the direction of the tension at all times, and by this plan the bars are made to do so.

If a cable bridge was formed upon this plan, would the part at which the joinings were made be equally strong with the other parts of the cable?—If made according to Mr. Telford's representation, I think the cable would break somewhere between, but not at the joinings.

Have you read over the statement delivered in this morning by Mr. Telford?—Yes, I have.

Do the data which he has taken for the construction of this bridge, appear to you to be sufficient for securing the degree of power which would be necessary for the construction of a safe bridge?—I think they are more than sufficient.

Does it appear to you that the different calculations of strength are accurate?—Mr. Telford seems to have taken his primary data from the fact of a bar of iron one inch square, suspended vertically, beginning to stretch at one half its absolute power. In all the experiments that I have witnessed of straining iron, I think none of the bars began to stretch permanently under nearly two-thirds; it appears to me, therefore, that Mr. Telford's data are perfectly safe

In the experiments that you have seen made on the strength of iron, has it required a force of from twenty-six to thirty tons to break a square inch of good bar iron?—Yes; I think the average weight with which they broke, amounted to twenty-nine tons nearly, as reported by that particular machine, namely, the hydraulic press

Will a cable made of square bars of iron be stronger than a cable made with links, each of them being the same weight?—Unquestionably.

Will you explain that?—I have said before, that a bar of iron, in order to sustain the greatest possible weight, should lie in the direction of the tension; links must necessarily be bent out of that direction.

Can iron, to be formed into bars, be depended upon, so that each bar should be of equal strength?—No; but no iron bar ought to be introduced into this bridge without being tried; and I dare say my friend Mr. Telford will take the precaution of trying every bar before he introduces it into the bridge.

Can it be sufficiently ascertained by experiment what bars are to be depended upon, and what are not, and explain the way?—According to the combination of bars which Mr. Telford has here proposed, each bar may be taken singly and submitted to the proof required.

In one of these hydraulic processes?—There are a variety of mechanical means of doing it; perhaps that would be as commodious a way as any. Every individual bar ought to be subjected to a proof, and there is no difficulty of devising the means of doing so.

Are not all the chain cables used by the navy submitted to a process of proof?—I believe they are.

Supposing this bridge to give way by an excess of pressure upon it; in which part of it do you think it would give way or break first?—Supposing the bars of iron to be of equal strength throughout, the fracture must necessarily take place near to the points of suspension.

What power of resistance, beyond the weight of the bridge itself, should you conceive was necessary to render it perfectly secure?—I believe Mr. Rennie said, that he would apportion the strength of the iron at four times the weight to be borne; I should think that would afford ample security; and if it was considerably less than that, it would do; because, in the experiments which I have witnessed on the strength of iron, I marked with particular attention this fact, that with sixteen tons the bar of one inch square began to stretch, or became permanently lengthened, and its sectional area became less; we released the tension, and again restored it to the same degree, the bar was not lengthened more than it was before; we suffered it to remain for some considerable time, perhaps a few minutes, but no alteration took place under this strain; we then added by degrees a greater weight, which brought on another longitudinal extension, that is, the bar was permanently lengthened, *Bryan Donkin, Esq.*

lengthened, so that no change appeared to take place in the length of the bar by the continuation of any weight until a greater weight was added, and then a further extension took place. It appeared as if a different arrangement took place among the fibres of the iron, so as to render them capable of sustaining a greater load.

If any one of the bars in the bridge, when first placed there, bears a greater weight than its neighbour or any other bar, and is disposed to stretch, would it accommodate itself to the length of the other bars?—From the fact I have just described, I suppose that accommodation must take place. If we suppose one of the bars to be shorter than all the rest, the whole weight of the bridge will be brought on that individual bar; the consequence would be, that that individual bar would be made longer until it became of an equal length with its neighbours, and as soon as it did so the neighbouring bars would take a corresponding weight.

Would it in that state bear as much weight as before it was stretched?—It would bear more weight without stretching.

You mean according to the experiments that you have seen tried?—Yes; I have tried other experiments besides these; I have tried with small wires, by actually suspending weights to those wires; and in making those experiments I found the fact to be the same.

Will not a given piece of iron drawn into wire support a greater weight than the original piece of iron from which the wire was drawn?—Yes, it will. I believe all iron, when drawn into wire, will bear a greater weight in proportion to its sectional area than bar iron.

Have you seen any instances of cables constructed upon the principle now recommended?—Never.

Will there be any difficulty in welding the small bars of iron to the length proposed by Mr. Telford, of fifty feet?—None in the world; I should not apprehend much difficulty in welding them for the whole length of the bridge.

Will the welded part, if the work is well executed for the fifty feet, be equally strong with the other parts?—If well done it will.

Is there any difficulty in having such work well executed?—No, I apprehend not. Any inefficiency of the workmanship would be detected by the proof that the bars would be put to before being applied to the bridge.

Then as the bars may be formed into lengths of fifty feet, and the several lengths be joined together in the manner proposed by Mr. Telford, so as to be as strong at the joining as at any other part, can there be any doubt of a cable formed of those lengths, so joined together, being equal to bear the weight it is proposed it should carry?—None in the world.